The

JUNIOR OFFICER'S HANDBOOK

on

SIMPLE NAVIGATION

by

WILLIAM ALEXANDER

The writer of this book has had considerable experience of navigation; he has navigated the liners of one of our largest steamship companies and also H.M. ships. He also took a course in H.M. School of Navigation. He has navigated aircraft, both civil and R.A.F. Recently at one of our Naval bases he was frequently approached by Junior Officers for advice on navigation: it is hoped that this book will be of assistance to them in their excellent work.

Second Impression

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ON

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CONTENTS

FOREWORD

The object of this book is to attempt to explain to the young officer who has had but little training or experience in navigation how to find his way about the seas.

Although plane or spherical trigonometry is used in most navigational problems the theory of trigonometry is not explained in this book. The simplest and quickest ways of working out the various problems are explained by "rule of thumb" methods.

It is hoped to follow this book with another in the same series on the theory of navigation, in which anyone who has read this book can go into the theory of trigonometry and nautical astronomy and understand how the various problems in navigation are worked out.

It is also hoped to publish a third book in the series on meteorology. Perhaps the readers of this book, having been bitten by the salt water bug, will, in the days after the war, find this book useful in navigating their peace-time commands. Let us hope it will be soon.

WILLIAM ALEXANDER

CHAPTER ONE

The shape of the Earth—Latitude and longitude— D. R. Navigation

The earth rotates about a diameter known as its axis, the ends of which are the North and South poles. The shape of the earth is an oblate spheroid, that is, a sphere slightly flattened at the poles. Since this flattening amounts to a difference in diameter of only 27 miles between that at the poles and that at the equator, the earth may be regarded for all practical purposes as a sphere.

Circles drawn on a sphere are known as either great circles or small circles; the great circles are circles whose plane passes through the centre of the sphere whereas small circles are circles whose planes do not pass through the centre of the sphere. The arc of a great circle passing through any two points on a sphere is the shortest distance between those points.

The equator is an imaginary great circle on the earth's surface whose plane is perpendicular to its axis. It divides the earth into two equal parts known as the Northern and Southern hemispheres.

Parallels of latitude are small circles whose planes are parallel to the plane of the equator.

Meridians of longitude are semi-great circles which join the poles and cut the equator at right angles. The Prime meridian is the meridian of Greenwich and is 0° of longitude. Other meridians are East and West of the Prime meridian until the 180th meridian is reached. The Prime meridian and the 180th meridian complete one great circle.

Latitude is measured from 0°, which is the equator, to 90° which are the poles, North and South.

The latitude of a place is the arc of the meridian between the equator and the place and is named North or South according to whether the place is North or South of the equator.

The longitude of a place is the angular distance East or West of the Prime meridian, measured along the equator to the meridian passing through the place.

The position of a place on the earth's surface is indicated by its latitude and longitude.

The difference in position between two places is indicated by Difference of Latitude or D.Lat. and Difference of Longitude or D.Long.

The D.Lat is the angular distance measured

along a meridian between the parallels of latitude passing through the two places.

The D.Long. is the angular distance, measured along the equator, between the meridians passing through the two places.

EXAMPLE.

A.	= Lat. 10° N.	Long. 20° W.
B.	= Lat. 8° N.	Long. 10° W.
A to B.	= D.Lat. 2° S.	D.Long. 10° E.
C.	= Lat. 3° N.	Long. 5° W.
D.	= Lat. 2° S.	Long. 4° E.
C to D.	= D.Lat. 5° S.	D.Long. 9° E.

It is obvious that a portion of the earth's surface, being convex, cannot be accurately represented on the flat surface of a chart.

There are various methods of drawing a graticule or network of parallels of latitude and meridians of longitude.

These are known as projections of which there are numerous kinds. The projection invariably used for charts used for sea navigation is known as Mercator's projection.

This is based on the cylindrical projection in which it is imagined that an enormous cylinder of paper is wrapped round the earth

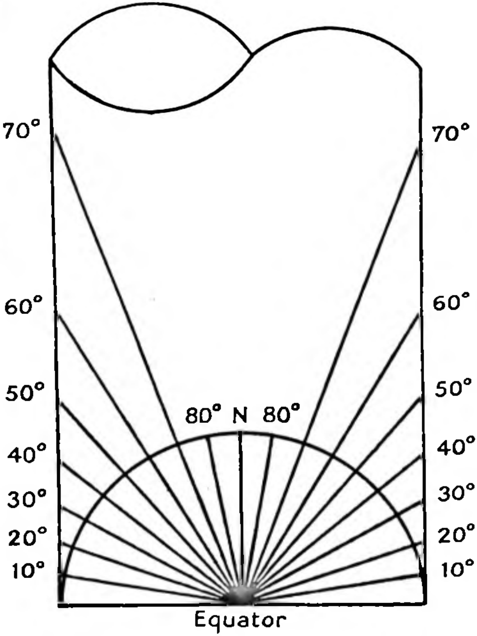

FIGURE I

THE TRUE CYLINDRICAL PROJECTION

touching it only at the equator and parallel to its axis.

A line is then taken from the centre of the earth through the meridians and parallels onto the paper and drawn there.

Figure 1 shows that this would lead to enormous distortion in the higher latitudes.

In Mercator's projection the meridians are parallel, as in the cylindrical, but the length of a minute of latitude varies as the secant of the latitude. The chart length of a minute of latitude at the equator is equal to the chart length of a minute of longitude on the equator.

The other minutes of latitude however vary as the secant of the latitude, the chart length of a minute of latitude at 60° being twice the chart length of a minute of longitude, the secant of 60° being 2.

The chart length of a minute of longitude remains the same all over the chart. This leads to distortion in comparative areas in the higher latitudes, the classic example being Greenland on a chart of the world by Mercator's projection. Greenland appears to be the same size as India whereas it is about a quarter the size and only looks the same size owing to being in a higher latitude.

In spite of this Mercator's projection possesses several advantages among them being:—

(*a*) All rhumb lines are represented on the chart as straight lines.

(*b*) Angles on the earth's surface are correctly represented on the chart.

The length of a minute of latitude is approximately equal to the length of one nautical mile and the chart length of one minute of longitude on a Mercator's chart is equal to the Cos. Lat. × the chart length of one minute of latitude; the longitude scale is therefore adjusted to the Cos. Mid. Lat. of the chart × the chart length of one minute of latitude at the middle latitude.

Since the lengths of the minutes of latitude on a Mercator's chart vary with the latitude, the scale of distance varies with the latitude, and so to measure distance on the chart it is necessary to measure along the latitude scale at the same latitude as the distance being measured.

A rhumb line is a line which cuts all meridian's through which it passes at the same angle. In order to find the course from one point to another on a Mercator's chart it is only necessary to draw a line between the points and measure the angle at which it cuts the meridians to find the true course to be steered. This is a rhumb line course and if the

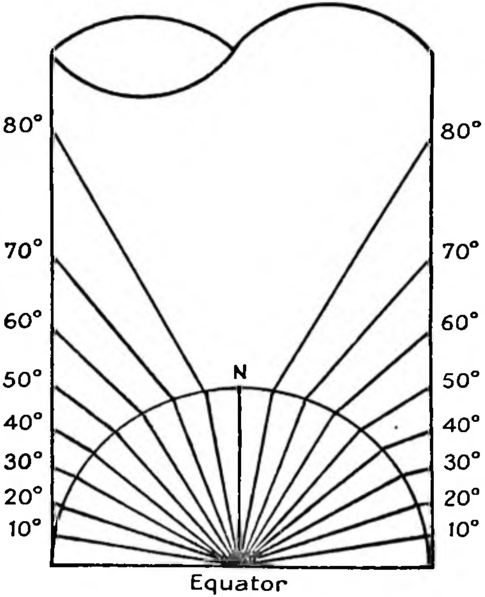

FIGURE 2
MERCATOR'S PROJECTION

ship makes good this course it will take you to your objective.

It is not always the shortest distance between

the two points, the arc of a great circle which cuts both points is the shortest distance. A great circle on a mercator's chart is a curve convex towards the nearest pole, and apart from the trouble of constantly altering course to keep on the great circle the saving in distance is negligible except for long distances in high latitudes.

In order to work out the course and distance between two points on a Mercator's chart we employ Mercator's sailing. This involves the use of meridional parts, which may be looked up in Inman's or Norie's tables. Meridional parts for any latitude are the increased lengths of the meridians on a Mercator's chart measured from the equator to the parallel and expressed in minutes of the longitude scale. By using the D.Long. and the difference of meridional parts (Mer.D.Lat) of two places on a Mercator's chart we are using units of the same length in order to solve right-angled plane triangles and find courses and distances to be steered or that have been made good.

The formula for finding the course or Co. is as follows:

$$\text{Tan. Co.} = \frac{\text{D. Long.}}{\text{Mer. D. Lat.}}$$

Having found the course, the distance is found by the formula:

$$\text{Dist.} = \text{D. Lat.} \times \text{Sec. Co.}$$

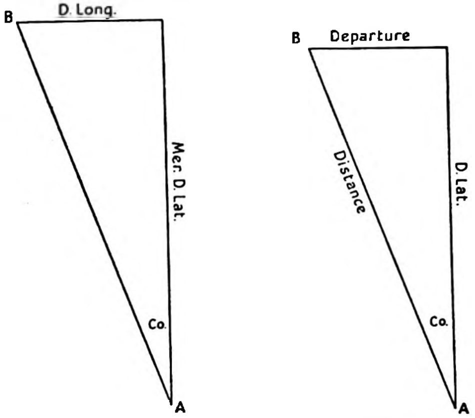

FIGURE 3

The worked example on page 20 shows the best way of laying out and working the problem.

When steering courses near East or West it is necessary to interpolate when taking out the Sec. Co. in order to get an accurate distance.

The latitude and longitude of a dead reckon-

Lat. A.	15° 45′ N.	Long. A.	12° 35′ W.	Mer. Lat. A.	957·13
Lat. B.	23° 50′ N.	Long. B.	15° 40′ W.	Mer. Lat. B.	1473·12
D. Lat.	8° 05′ N.	D. Long.	3° 05′ W.	Mer. D. Lat.	515·99

D. Lat. 485′ N.

D. Long.	185′ W. =	2·267172
Mer. D. Lat.	515·99 N. =	2·712640
Tan. Co. =	N. 19° 43′ W. =	9·554532
Sec. Co. =	N. 19° 43′ W. =	10·026261
D. Lat.	485′ N. =	2·685742
Distance	515 miles =	2·712003

The distance is of course in nautical miles.

ing position after steering a certain true course for so many miles from a departure point or fix can be found by means of Traverse tables which are found in Inman's or Norie's tables. By entering the tables with the true course and distance the D. Lat. and Departure are found. Departure is D. Long. expressed in units of the same length as the D. Lat. Departure can be converted to D. Long. by the formula:

$$\text{Departure} = \text{D. Long.} \times \text{Cos. Lat.}$$

If there is any D. Lat. the Mid. Lat. has to be used.

$$\text{Departure} = \text{D. Long.} \times \text{Cos. Mid. Lat.}$$

also

$$\text{D. Long.} = \text{Departure} \times \text{Sec. Mid. Lat.}$$

The D. Long. can however be found from the traverse tables by looking up the Mid. Lat. as though it were the course and entering the D. Lat column with the departure, the D. Long. will be found in the distance column. With interpolation this will be found to be quite accurate enough. You now have the D. Lat. and the D. Long.; by applying these to your departure position or fix, you have your dead reckoning, or D.R. position. You will know

how to apply these by the true course. If your true course was North 20° West, your D. Lat. is North, and your D. Long. West.

EXAMPLE.

Departure position.

Lat.	15° 45′ N.	Long.	12° 35′ W.
D. Lat.	8° 04′ N.	D. Long.	3° 07′ W.
Lat.	23° 49′ N.	Long.	15° 42′ W.

D.R. Position.

True Course. N. 20 W. 515 Miles. Traverse table. D. Lat. 484 N. Dep. 176 W. Entering traverse table at Course 20° for Mid. Lat. and D. Lat. column at 176. the D. Long. is found in the distance column as 187 W. Apply above and D.R. Position will be found.

CHAPTER TWO

The Compass—Variation—Deviation

A magnetic compass consists of a suitable magnetic system supported on a pivot inside a compass bowl.

In most of His Majesty's ships the magnetic compasses are of the liquid type. This means that the bowl is filled with liquid. This not only damps out the oscillations of the magnet system but reduces the weight on the pivot. The bowl is slung in gimbals and pendulated so that it remains in a horizontal position when the ship rolls or pitches.

The top of the magnet system consists of a card which is graduated in degrees and points of the compass.

The North and South points of the card point in exactly the same direction as the North seeking and South seeking ends of the magnetized needles. The needles are at least two in number in order to allow the pivot to support the system in the centre.

The North-seeking end of the needles is known as the Red pole and if it were influenced by the earth's magnetic force alone would

point to the magnetic North along the magnetic meridian. The South-seeking end is known as the Blue pole.

In a steel ship, however, there is always what is known as Deviation which deflects the compass needles according to the direction in which the ship is heading. This is discussed later in the chapter.

In the previous chapter true meridians have been explained as imaginary lines on the earth's surface pointing in a true North and South direction. The magnetic meridian is the horizontal direction in which a freely suspended magnetized needle influenced only by the earth's magnetic field would point.

The angle between the true meridian and the magnetic meridian at a certain place is known as the Variation.

If the North-seeking end of the needle points to the West of the true meridian, then the Variation is known as Westerly. If to the East then it is Easterly. The variation is different in different places and it changes slightly from year to year.

It can be found by reference to a Variation chart, or by the compass rose of a chart where the variation for a certain year is given and the annual change. Lines of equal variation or

isogonals are often drawn on the chart but again must be corrected up to date.

In large-scale plans the variation is sometimes given in the title of the plan.

In converting a magnetic bearing or course to true, Westerly variation must be applied in an anti-clockwise direction and Easterly clockwise. Naturally, when converting from true to magnetic the reverse is the rule. Magnetic compasses in ships are also affected by what is known as Deviation. This is a very elusive factor and liable to change.

It alters with every new direction of the ship's head, if the ship has a list, with change of magnetic latitude, or sometimes for no apparent reason at all.

The compass adjuster, when "swinging ship," reduces the deviation as much as possible but he cannot entirely eliminate it.

I cannot too strongly urge officers to check their deviation every four hours and at every alteration of course. This is the rule in the Merchant Navy, and I think if they can do it, the Royal Navy should be able to. I quite realize the difficulty owing to the awkward placing of compasses in some small ships, but at any rate amplitudes should always be obtained when possible. They do not take a minute to

work out. The method is explained later in this book.

Deviation is caused partly by the soft iron in a ship in which magnetism is induced by the earth's magnetic field.

Since, in correcting compasses, it is the endeavour of adjusters to correct like by like, this cause of deviation is counteracted by the soft iron spheres, or quadrantal correcters, and also by the Flinders bar in the brass sheath attached to the forward part of the binnacle.

Once adjusted, it should not be necessary to alter these soft iron correcters unless the compass is shifted or structural alterations are made to the ship.

The greatest cause of deviation is the permanent magnetism of the ship. If a piece of steel is fixed in a certain position and hammered it will assume magnetic properties according to the direction in which it is fixed. It will be magnetized in the direction of the earth's magnetic field. In the same way a steel ship is magnetized by the hammering and riveting during building and assumes magnetic properties in the direction of the earth's magnetic field.

The earth's magnetic field is not a horizontal force (except at the magnetic equator), it

points downwards at the angle of magnetic dip or magnetic latitude and also in the direction of the magnetic meridian. The angle of magnetic dip in Southern England is about 67°.

So if a ship were built of steel and heading magnetic North in England she would become a magnet with a North-seeking pole or Red pole under the forward part and a Blue pole above the after part.

Since the effect of a magnet on the compass decreases very rapidly with its distance from the compass the permanent magnetism of the ship can be counteracted by small magnets of opposite force fitted in the binnacle. These small magnets are fitted vertically, fore and aft, and athwartships, and by adjusting the number of these magnets and their proximity to the compasss the deviation can be reduced to a minimum.

It may be asked why, since the compass needles are horizontal, it is necessary to worry about vertical magnets? This is done on account of heeling and rolling, when the compass comes to one side of the vertical force, and if it were not done the card would swing 40° to 50° either side of the course as the ship rolled.

I do not advocate anyone but a qualified compass adjuster or Specialist (N) Officer in

the Royal Navy touching the magnets in the binnacle of a compass; but it may, under exceptional circumstances, be necessary.

I will give a simplified method of swinging ship for deviation.

(*a*) Put ship on North magnetic. Find deviation by transit bearings or by azimuth. Correct all the deviation by means of the athwartships magnets.

(*b*) Put ship on East magnetic. Find the deviation and correct all of it by fore and aft magnets.

(*c*) Put ship on South magnetic. Find the deviation and correct half of it by athwartships magnets. Enter the deviation on the card.

(*d*) Put ship on West magnetic. Find the deviation and correct half of it by fore and aft magnets. Enter the deviation on the card.

(*e*) Put ship successively on NW, N, NE, E, SE, and SW, and enter deviations on the card.

You should obtain information locally with regard to procedure with vertical magnets in the event of a breakdown as I am not allowed to write about this in war-time. These magnets

are important as I mentioned before, because of the excessive swinging of the compass during rolling if they are not properly adjusted.

Deviation is, like variation, named East and West. If the compass needle points to the East of the magnetic meridian the deviation is East and if to the West it is West. In converting compass bearings or courses to magnetic, West is applied anti-clockwise and East clockwise. If you are converting magnetic courses or bearings to compass the reverse is the rule.

The algebraic sum of the variation and the deviation is known as the Compass Error.

Always remember that variation changes with place and deviation with the ship's head.

CHAPTER THREE

Chartwork and Coastal Navigation

The practice of taking frequent bearings whilst navigating around the coast is apt to be neglected.

Cross bearings of, if possible, at least three different objects should be taken every half an hour, preferably exactly at the hour and half hour. By this means the Commanding Officer, the Navigating Officer, and the Officer of the Watch will know what course and speed the ship is making good.

All should know the expected direction and strength of the tide, which can be obtained from various books of tidal streams, or very often from the chart itself. Flood tides are marked by arrows with feathers on one side and ebb tides by arrows with no feathers. The rate at which it runs at Springs and at Neaps is often also marked.

It is as well also to know the International system of buoyage.

In channels which are buoyed the can or barrel-shaped buoys are on the port side going with the main stream of the flood tide. Conical buoys are on the starboard side.

Banks or shoals in the channel are marked at either end by buoys with top-marks, the seaward end buoy having a top-mark shaped in a diamond and the landward end a triangle. As the sailors say "go to sea for diamonds and come home for Bass." This knowledge is very useful in thick weather; if a buoy is suddenly sighted close ahead it as well to know which side of it to go. If in extreme doubt go very close to it as there is invariably a margin of safety between the buoy and the danger.

Piloting a ship in or out of harbour should not be done by the compass but whenever possible by transit bearings. The compass can only tell you the direction in which the ship is heading and the tide may sweep you to one side or the other.

Prepare your chart before entering or leaving and select transit bearings which will keep you on a safe course.

Select also if possible transit bearings on your beam for your alter course positions, or if this is impossible, compass bearings of objects on the beam. You may write on these courses the compass courses as this will not only assist you in getting on to them but will give you a check on your deviation on those courses.

When navigating around the coast and you

have only one object to take a bearing of, the only method of fixing your position by bearings is by what is known as the running fix.

The most favourite form of running fix is the four point bearing.

This is a simple geometrical problem, as the figure shows.

Take a bearing of an object when it is bearing four points or 45° on the bow, taking the time or reading the patent log at the same time. Take another bearing when it is abeam and take the time or read the log again. The distance run between the first and second bearings is the distance off the object at the second bearing as long as there is no tide or current.

A sextant angle is sometimes practicable when the object is abeam, the distance off may be found very accurately with Lecky's Danger Angle Tables. In Fig. 4 the four point bearing method of getting a position by means of a running fix is illustrated. It will be seen that the triangle consisting of the first and second bearings and the course make an isosceles triangle. Another method utilizing the isosceles triangle is known as "doubling the angle on the bow." For example, if a light were sighted bearing 30° on the bow, the distance the ship runs between then and when the light is bearing

60° on the bow is the distance the ship is off the light at the second bearing. The four point bearing is just a special example of this with the

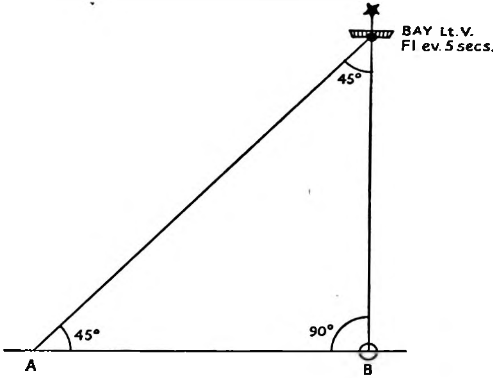

FIGURE 4

FOUR POINT BEARING

advantage that the light is on the beam at the second bearing.

Running fixes can also be used from any two bearings of an object as the ship passes it; the angle between the two bearings should be as broad as possible up to 90°.

In Fig. 5 an example of a running fix by the above method is shown. At 0900 Bald Head

Lt. Ho. bears 048°(T). The speed of the ship is 15 knots. At 0930 Bald Head Lt. Ho. bears 320°(T). Draw this bearing line on the chart.

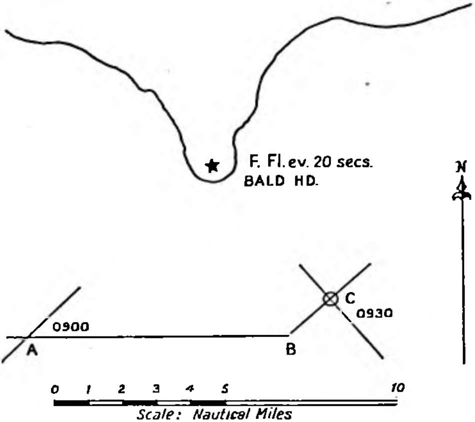

FIGURE 5

RUNNING FIX

A to B is 7.5 nautical miles, so B is where the ship should be by dead reckoning from A. From B draw a line parallel to the first bearing (048°). Where this line cuts the second bearing line is the position at 0930. Running fixes are useful but should not be used when cross bearings can be taken, as they are dependent for

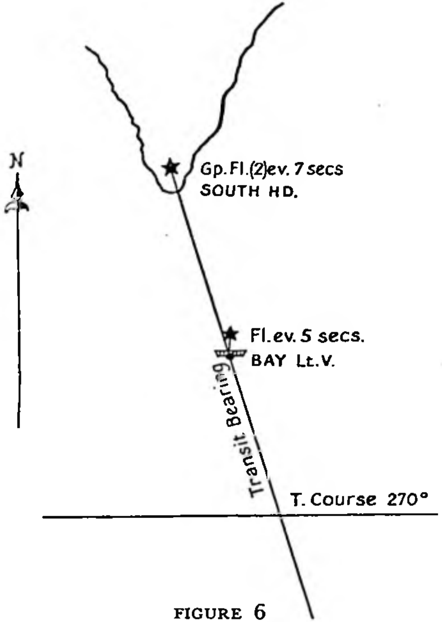

FIGURE 6

TRANSIT BEARING

their accuracy on the course and speed of the ship being maintained and do not allow for tides or currents which may be experienced.

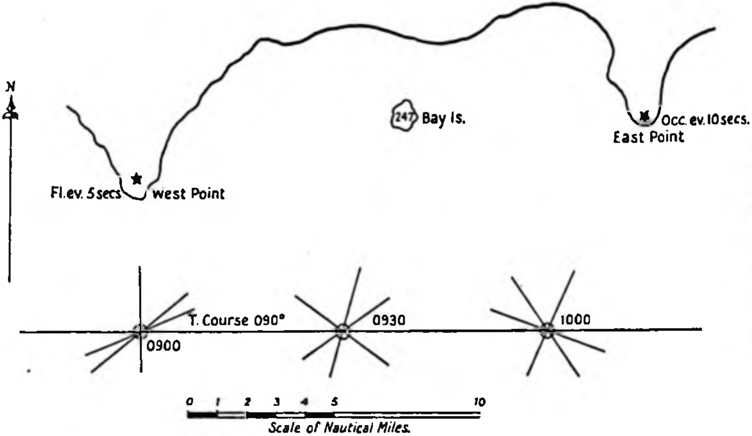
N
247
Bay Is.
Occ. ev. 10 secs.
East Point
Fl. ev. 5 secs
west Point
T. Course 090°
0900
0930
1000
0 1 2 3 4 5 10
Scale of Nautical Miles.

FIGURE 7

In Fig. 6 a transit bearing is shown; this only gives one position line, but this position line is a very accurate one and is especially useful in checking the error on the compass. By taking a compass bearing when the light-house and light-vessel are in transit and comparing it with the true bearing as taken from the chart an accurate compass error is found.

If later cross bearings of the two objects are taken using the compass error just found, an accurate position can be fixed.

In Fig. 7 cross bearings are shown of three objects. This is an example of coastal navigation under ideal conditions with three conspicuous objects of which to take bearings.

Before closing this chapter I would like to give one hint with regard to keeping station when in company with other ships. An increase of speed of 1 knot for 6 minutes will bring you 1 cable nearer your next ahead. A decrease of speed of 1 knot for 6 minutes will drop you back 1 cable. The effect is not immediate, naturally, owing to inertia but the effect is sure and is a useful tip to remember Of course, half, or quarter cables out of station can be adjusted in the same way, remembering the rule: One knot—six minutes–one cable.

CHAPTER FOUR

The Sextant—The Azimuth Mirror

The *Sextant* is an instrument for measuring angles, either vertical or horizontal. It owes its name to the fact that the limb or arc of the instrument measures at least 60° of arc or one-sixth of a circle. A quadrant would measure at least 90°, and an octant at least 45°.

The optical rule is that if a ray of light is reflected twice in the same plane by two reflectors, the angle between the first and last direction of the ray is twice the angle between the reflectors. (See Fig. 8.)

In Fig. 8 the horizon glass is represented by H, and the index glass by I. R is the ray from the object being observed which strikes the index glass at an angle of 45°. Since the angle of incidence is equal to the angle of reflection, the ray leaves the index glass at an angle of 45°. It then strikes the horizon glass at an angle of 67½°, it leaves the horizon glass at an angle of 67½° and goes to E, which is the eye of the observer. The angle at A is the angle between the mirrors which is 22½°. The angle at E is the angle between the first and last directions of

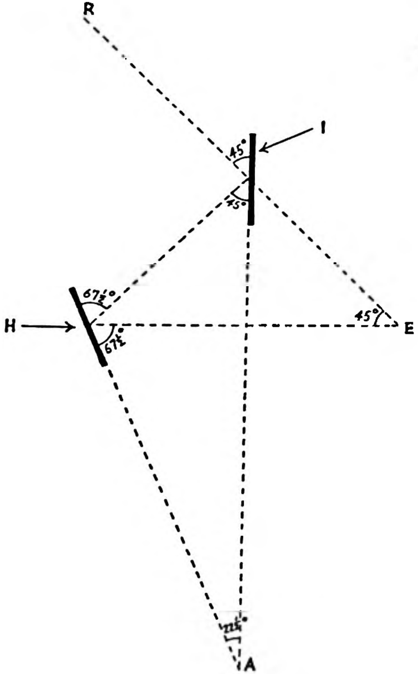

FIGURE 8

THE PRINCIPLE OF THE SEXTANT

the ray from R and is 45°. This can be proved by geometry but I do not think that this is necessary in this book.

The explanation of the above rule was neces-

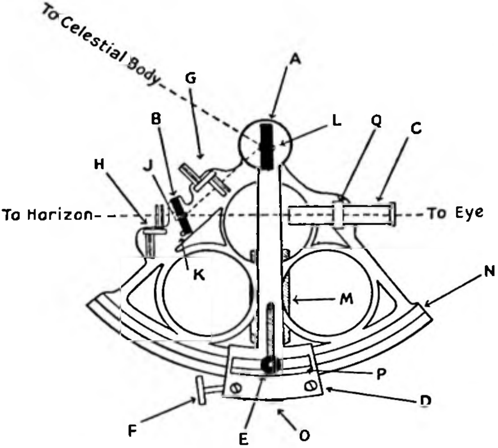

FIGURE 9
THE SEXTANT

sary in order to show that although the limb or arc of a sextant only measures 60° of arc, angles of up to 120° can be measured by this instrument.

In Fig. 9 a rough diagram of a sextant is shown in order to point out and explain the use of the various parts.

A is the index mirror which is fixed on the index bar D which is free to rotate on an axis which is directly under the centre of the reflecting surface of A. The index bar can be moved to any position on the arc N, and can be fixed in any position by means of the clamp screw O.

The index bar can then be adjusted more accurately by means of the tangent screw F, and the accurate reading of the angle may be found by means of the arc N and the vernier P. Most sextants are cut so that the angle can be measured to the nearest 10 seconds of arc. This is done by reading the degrees and nearest 10 minutes on N where the arrow on the right hand end of P points. The microscope E is used to assist in this. It will be seen that the vernier scale is marked from the arrow, which is 0 minutes, up to 10 on the left-hand end which is 10 minutes. Only the even numbers are actually numbered. It will be seen that each division of 1 minute is subdivided into six sections which are equivalent to 10 seconds.

In order to read the angle shown to the nearest 10 seconds, read the degrees and

nearest 10 minutes on N at the arrow; then, with the assistance of the microscope see which cut or line on the vernier P is exactly opposite to a cut or line on N. See how many divisions and subdivisions this is from the arrow, and calling the divisions minutes and the subdivisions tens of seconds add this to the degrees and tens of minutes already read off and the accurate reading is given.

To return to the description of the diagram, the horizon glass is B. This is a glass the lower half of which is mirrored in order to reflect the rays from A, the upper half is clear in order that the horizon may be seen through it from the telescope C and an angle between the celestial body and the horizon found. G and H are coloured shades; G is used when taking observations of the sun in order to dim it, and H when the glare of the sun on the sea makes it difficult to take an angle.

C, as mentioned, is the telescope and can be focused; it is held in position by the collar Q which can be raised or lowered in relation to the plane of the instrument by means of the screw underneath.

M is the wooden handle by means of which the sextant is held in the right hand. Applying the eye to the telescope C, the index bar D is moved

to an approximate altitude of the body being observed. D is then clamped in place by means of O and finer adjustments are made by means of F.

When the altitude is exact, the observer shouts out "time" or "stop" and the exact time is taken by someone watching the deck watch or chronometer and noted. The exact altitude is then read off and noted together with the ship's time, used in order to work out the D.R. position.

I would advise anyone taking sights to practise, when taking the sight, to rotate the sextant a few degrees in arc either side of the vertical; by this means the body being observed will appear to move in a small arc above the horizon, touching it at only one point which is the true altitude. Inexperienced observers are apt to hold the sextant in such a way that it is not quite vertical and the angle observed is greater than the correct angle. The correct angle is the angle between the body and the horizon immediately beneath it; if the sextant is not held vertically at the time of the observation the angle measured is between the body and the horizon to either side of the part of the horizon immediately beneath it; the angle measured is thus too large and an incorrect position line obtained.

There are several errors to which a sextant is liable; I intend in this book to only deal with the three commonest and most easily adjustable ones. I will mention the others and hope to describe them fully in a later book. The first error is that known as the error of perpendicularity, that is, if the index glass is not perpendicular with the plane of the instrument. It is found and adjusted as follows. Hold the sextant in your left hand, face up and arc away from you. Set the index bar about half way along the arc and clamp it, then, looking in the index mirror, see if the true and reflected images of the arc form one straight line. If they do, there is no error, if they do not you can adjust it until they do by means of the screw on the back of the index glass marked L in the diagram.

The second error is known as the error caused by the horizon glass not being perpendicular to the plane of the instrument.

It is found and adjusted as follows. Set the index bar to exactly zero; then hold the instrument horizontal and look through the telescope at the horizon. If the true and reflected images of the horizon are in one straight line there is no error, if not, then the error can be eliminated by means of the screw at the top on the

back of the horizon glass, marked J in the diagram.

The third error is when the index and horizon glasses are not parallel to each other with the index bar clamped at zero.

It is found and corrected as follows. Set the index bar to exactly zero; then hold the instrument vertically and look through the telescope at the horizon. If the true and reflected images of the horizon are in one straight line there is no error, if not, then the error can be eliminated by means of the screw at the bottom and side of the back of the horizon glass, marked K in the diagram.

The last two adjustments are better made at night by means of a star as they are liable to offset each other; by means of the star method these two adjustments can be made simultaneously as follows. Set the index bar to zero and look up through the telescope to any fairly bright star. If the true and reflected images of the star are horizontally apart, adjust with the top screw, if vertically, adjust with the bottom side screw. By adjusting both these screws the true and reflected images can be made to come together and the adjustments are correct.

Many sextants have an index error which is a slight error caused during the manufacture of

the instrument. This error varies with the angle being measured and should be allowed for; a card showing the index error for a particular instrument is found in the lid of the case containing the instrument.

Other errors from which sextants sometimes suffer, or their owners do, are collimation error, which means that the axis of the telescope is not parallel to the plane of the instrument.

Centring error, which means that the axis of the arc round which the index bar revolves is not quite the same as the centre from which the arc was cut or graduated.

Shade error, which means that the two faces of the shade are not ground parallel to each other.

Graduation error, which means that the arc has not been accurately cut and graduated.

Vernier error, which means that the vernier has not been accurately cut and graduated.

The latter four errors are not found in good instruments manufactured by reputable firms.

The sextant should be kept clean by means of a chamois leather cloth and occasionally a little oil or vaseline wiped over the metal parts and wiped off again. Never use either silver or metal polish on the arc or vernier. Keep the glasses and telescopes clean and always give

the sextant a wipe over if it has been wetted by spray or rain. If the reflector surfaces in the mirrors get tarnished have them resilvered, as it makes stellar observations much easier.

Check the sextant frequently for the three errors described and adjust if necessary; the sextant is a very delicate instrument and any knock or blow will cause an error to creep in.

The *Azimuth Mirror*, of which a rough diagram is shown in Fig. 10, can be used for taking azimuths of celestial bodies, in order to find the compass error and deviation; it can also be used for taking bearings of objects ashore or of other ships.

In the diagram, A is the prism, B are the shades used when taking azimuths of the sun, C is the milled-edge knob by which the setting of the prism can be adjusted, D is what is known as a shadow pin and can be used under favourable circumstances for taking azimuths of the sun, the shadow cast by the pin from the sun on the compass card is the reciprocal of the compass bearing of the sun, E is a spirit level which tells you when the instrument is level.

In order to take azimuths the arrow marked on C must be pointing upwards; by leaning over the instrument so that you are looking

down the tube of the instrument onto the compass card and by adjusting the prism by means of C you can get a reflection of the

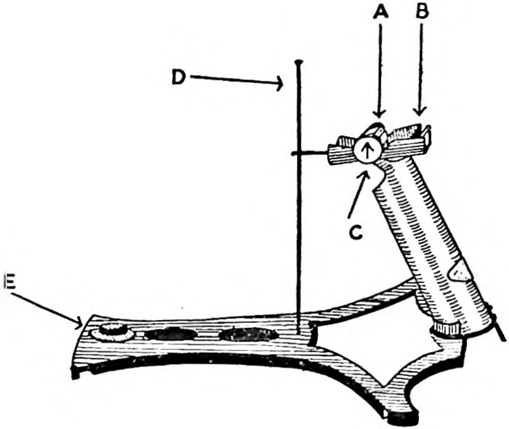

FIGURE 10

AN AZIMUTH MIRROR

celestial body on the prism. By adjustment this reflection can be brought to the edge of the prism and just above the edge of the compass card, a compass bearing of the body can then be read off. If the ship is rolling and the card

swinging about, the mean of the bearings over a space of a minute should be taken.

When azimuths of the sun are being taken the shades B can be used.

When taking bearings of objects at approximately sea level or up to 5° altitude the arrow on C should be pointing downwards and the level of the observer's eye at approximately the same level as the prism.

By adjusting C the reflection of the edge of the compass card can be seen in the prism, by adjusting the height of the observer's eye and the angle of the prism, the object, the reflection of the edge of the compass card, and the observer's eye can be brought into line. The compass bearing is then read off the reflected edge of the compass card.

CHAPTER FIVE

Time and the "Nautical Almanac"

Greenwich Mean Time, or G.M.T., is the basis of all time used in navigational problems. 12 00 hours G.M.T. is the mean of the times throughout the year at which the sun crosses the meridian of Greenwich. (It is easier from the point of view of description to regard the sun as crossing the meridian, although, of course, it is the rotation of the earth which brings the sun's bearing 180° from Greenwich.) The earth rotates around its axis every 24 hours, but it also moves around the sun, following the path of an ellipse or oval, every 365¼ days. Since its path is an ellipse and not a circle with the sun as centre its angular speed around the sun is not regular and so the sun does not cross the meridian of Greenwich at exactly 12 00 hours every day. The time at which the sun does cross the meridian of Greenwich is known as apparent noon at Greenwich or 12 00 hours apparent time. The difference between Apparent time and Mean time is known as the equation of time. This used to be given in the *Nautical Almanac* and was additive or subtrac-

tive. It is still given in the *Nautical Almanac* but has had 12 00 hours added to it, and is known as "E"; it is always additive.

The time at which the sun is on the meridian at any particular place is 12 00 hours Apparent time at that place or A.T.P. (This is often known as A.T.S. or Apparent time at ship.) To find this the Mean time at place or ship (M.T.P. or M.T.S.) has to be calculated. The difference between M.T.S. and G.M.T. is the longitude of the place expressed in time. Since the earth completes one rotation or 360° every 24 hours, it rotates 15° every hour. Therefore if the longitude of a place is divided by 15 the result will be the longitude in time of that place expressed in hours, minutes and seconds.

EXAMPLE

Longitude. 107° 43′ divided by 15 = 7 hours, 10 minutes, 52 seconds.

After a little practice this calculation can be done mentally, but a good and quick method is to turn to the Haversine table in Norie's or Inman's tables where the haversines can be read off for either angles of arc or time; by comparing the longitude in arc with the reading in time the longitude in time can be read off.

It is now necessary to find out whether to

add or subtract this longitude in time to or from G.M.T. I have always found the following couplet very useful when in doubt:

> Greenwich time least, longitude East.
> Greenwich time best, longitude West.

Therefore, by finding the factor "E" from the *Nautical Almanac* at the G.M.T. and adding it to the M.T.S. the A.T.S. can be found.

Since the earth is a sphere and nearly all navigational problems are solved by the solution of triangles on that sphere, spherical trigonometry has to be used. I do not propose to broach the subject of spherical trigonometry in this book as it is rather complicated and the object of this book is to try to explain to the young navigator as briefly and simply as possible how to find his way about the ocean. It is, however, necessary to explain the various parts of the various triangles to be solved so that the observer will have some idea of what he is trying to do although his methods of doing it will be purely "rule of thumb."

The position of a place on the earth's surface is indicated by means of latitude and longitude, but in order to find the position of a place on the earth's surface by means of celestial observations it is also necessary to have some means

of expressing the positions of the celestial bodies observed. When looking up into the sky on a clear night you may perhaps see a star which appears to be directly above you, if it is actually directly above you then it is at your zenith.

The celestial latitude and longitude of that star will therefore be the same as your celestial latitude and longitude. Latitude in the celestial concave is expressed as the Declination and longitude as the Right Ascension. The Declination and Right Ascension of all the principal celestial bodies are given in the *Nautical Almanac*; those for the sun, moon and planets have to be interpolated or corrected for accuracy, but those for stars change very little and are given for the month.

It is usual in navigational problems to imagine the spherical triangle to be solved as being in the celestial concave; I prefer, however, to imagine the triangle as being on the earth's surface, with the three corners of the triangle as follows: O the D.R. position of the observer, P the pole nearest to the observer, and X that point on the earth's surface which is directly underneath the body being observed.

The side OP is known, since it is 90° minus the latitude of the observer. The side OX is known, since it is 90° minus or plus the decli-

nation of the body. It is minus if the latitude and declination are both North or both South and plus if one is North and the other South. The angle at P is known, since it is the difference in longitude between O and X expressed in time and is known as the Hour angle of the body. The method of solving this triangle and from it getting a position line is explained in Chapter Seven.

It is now necessary to consider Right Ascension.

The axis of the earth is not at right angles to the plane of the ellipse or path which the earth follows round the sun but is canted at an angle of $23\frac{1}{2}°$ from the perpendicular. This is the cause of the seasons. When the North pole is canted away from the sun the Northern hemisphere does not get as much sun as the Southern so it is winter in the North and summer in the South. When the North pole is canted towards the sun it is summer in the North and winter in the South. In Fig. 11 the path of the earth around the sun is shown with the seasons marked as they affect the Northern hemisphere.

To return to the celestial concave, we have two imaginary circles there. One is in the same plane as the equator and is known as the equinoctial. The other is in the same plane as

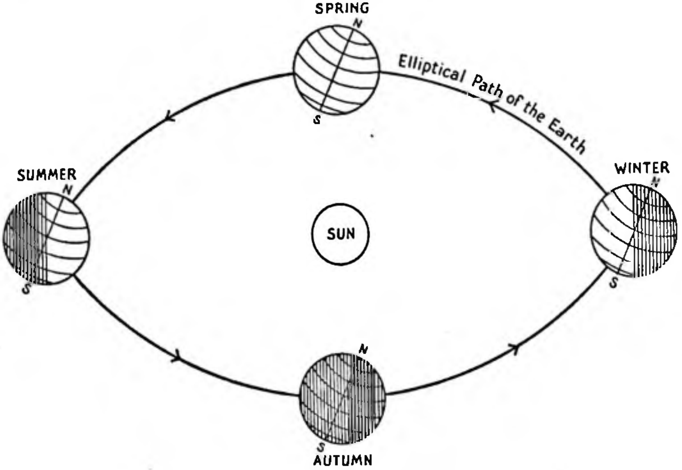
SPRING
N
S
Elliptical Path of the Earth
SUMMER
N
S
SUN
WINTER
N
S
N
S
AUTUMN

FIGURE II

the ellipse or path of the earth round the sun and is known as the ecliptic. These two circles cut each other at two places; the first is known as the First point of Aries and is the point from which all celestial longitude or Right ascension is measured. (See Fig. 12.)

It is only necessary to be able to express the observer's position in the same terms, that is,

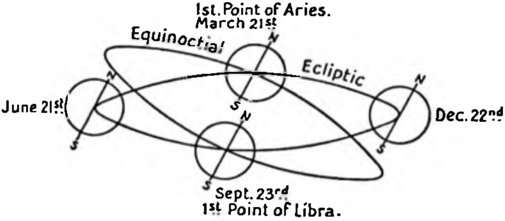

FIGURE 12

to find the Right ascension of the observer's meridian. This is done by finding the Right ascension of the mean sun in the *Nautical Almanac* which is under the letter "R" in the pages on the sun.

Add "R" to the Mean time at ship, or M.T.S., and the result is the Right ascension of the meridian, or R.A. Mer. The difference between the R.A. Mer. and the R.A. of the body is the Hour angle or H.A. of the body.

This is equivalent to the difference in longitude between O and X in the triangle and is equal to the angle at P.

In the *Nautical Almanac* the first page is devoted to the principal stars; the magnitudes are given for each, the brightest being Sirius with $-1\cdot6$, to others with up to $+2\cdot6$. The R.A. and Declination of each is also given. On the next page details of the moon are given and will be described more fully in the chapter on the moon. The next few pages are on the sun, and give the values of "R", "E", and Declination for every two hours; a book marker of proportional parts is used for getting the nearest value of "R". The next few pages are on the moon and give the R.A. and Dec. for every two hours. The table of proportional parts at the end of the book has to be used to accurately find the R.A. and Dec., the differences between each two hours being given. The last two pages are on the four principal planets, Venus, Jupiter, Saturn and Mars. The R.A. and Dec., given for 00 00 hours of each day, can be correctly found by means of the daily change and the table of proportional parts at the end of the book.

The *Nautical Almanac* also contains tables for finding the latitude by observation of the pole

star; the method for this is explained in Chapter Eight. Tables are also given for the times of sunset and sunrise and also moonset and moonrise. The former is very useful for finding the approximate time at which morning and evening star sights can be taken and thus enabling the observer to decide which will be the most suitable stars to use and also to calculate the approximate altitudes and bearings in which to look for them. The approximate bearings and altitudes can be found either by means of a star globe, if there is one supplied to the ship, or by means of Altitude-Azimuth tables.

This is especially useful for evening stars, as, by setting the sextant at the approximate altitude and searching in the direction of the approximate bearing, stars can usually be picked up on the sextant and observations taken while there is still a perfect horizon.

The Mean time of sunset and sunrise for various latitudes is given for dates throughout the year in the tables in the *Nautical Almanac.*

As ships do not generally keep Mean time on their clocks it is necessary to find the ship's time at which the sun will rise or set. First of all, look up the mean time of rising or setting in the table and make a note of it. Then work out the Mean time at ship at the time at which

the observations will be taken. M.T.S. = G.M.T. $\pm$ Long. in time. Then compare the difference between ship's time and G.M.T. and M.T.S. and G.M.T. The difference between the two differences from G.M.T. is the correction to be applied to the Mean time of sunrise or sunset to reduce it to ship's time. Twilight exists theoretically from when the sun is 18° below the horizon until sunrise and from sunset until the sun is 18° below the horizon, but half an hour before sunrise and after sunset is usually the best time for taking star sights.

CHAPTER SIX

Amplitudes—Azimuths—Altitude corrections—Meridian and ex-meridian altitudes

The Amplitude of a body is its bearing when it is just rising or just setting and is a very simple way of finding the error on a magnetic compass.

Not only is the calculation required very simple, but in some small ships where the standard compass is in an enclosed house on the bridge it is only possible to take bearings of objects at low altitudes.

Amplitudes can be taken of the sun, moon, planets or stars, but are more generally taken of the sun as it is brighter and therefore easier to take. Owing to refraction being greatest at low altitudes the sun appears to rise before it reaches the continuation of a line from the observer's eye to the horizon. The amount of this refraction is about 33′ or about the diameter of the sun.

Since the amplitude given in the tables is worked out for when the centre of the sun is in a line with the horizon and the observer's eye, the bearing by compass should not be taken until the sun appears to be 33′ above this, or

when there is a space between the bottom of the sun and the horizon equal to half the diameter of the sun.

Setting amplitudes should be taken in the same way.

Having taken the compass bearing at this time it is necessary to look up the declination of the body in the *Nautical Almanac* and with this enter the Azimuth tables with the latitude of the ship.

It will be found that the latitude is given in two places in the tables; one section is marked "Declination same name as Latitude" and the other "Declination contrary name to Latitude." Therefore, if the latitude and declination are both North or both South look up the former section, but if one is North and the other South look up the latter.

Having turned to the page with the latitude of the ship, look down the column with the declination of the body and right at the bottom of the column on the second page the rising and setting amplitude will be found. It will probably be necessary to interpolate between the pages of latitude and columns of declination to get the nearest result. The amplitude is East if the body is rising and West if setting. It is North if the declination of the body is North, and South if the declination of the body is South.

The difference between the observed amplitude and the true amplitude is the total compass error; by applying the variation the deviation can be found.

EXAMPLE

In Lat. 50° N. the sun's setting amplitude was N. 65¼° W. on a compass course of N. 60 W.
From the *Nautical Almanac* the sun's declination was 5° N.
From the Azimuth tables the true amplitude was N. 82¼° W.

True Amp.	N. 82¼° W.
Obs. Amp.	N. 65¼° W.
Compass Error.	17° W.
Variation.	15° W.
Deviation.	2° W.

The amplitude can also be worked out without the aid of Azimuth tables by means of the formula:

$$\text{Cos. Amp.} = \text{Sin. Dec.} \times \text{Sec. Lat.}$$

EXAMPLE AS ABOVE

Dec.	5°	Sin. =	8·940296
Lat.	50°	Sec. =	10·191933

T. Amp. 82° 12′ Cos. = 9·132229 = N. 82° 12′ W.

Azimuths of the sun, moon, planets or stars can be taken whenever these bodies are visible and are not at too great an altitude.

The reason why the altitude should be low is because a more accurate bearing can be taken by means of the azimuth mirror under those conditions. It is also better to take azimuths when the body is bearing as near East or West as possible since the bearing is changing less rapidly and more time can be taken in getting an accurate bearing.

Azimuth tables that are usually used are Davis's Azimuth tables which cover latitudes from 0° to 30° with declinations from 0° to 24°, the Admiralty Alt-Azimuth tables which cover latitudes from 30° to 64° and declinations from 0° to 24° and also two volumes of star azimuth tables for the higher declination stars.

Azimuths can also be worked out from Norie's or Inman's tables for any latitude or declination.

The three factors required for entering the tables are: (*a*) The latitude of the ship. (*b*) The declination of the body from the *Nautical Almanac.* (*c*) The hour angle of the body.

The hour angle of the sun is found in a different way to that of the moon, planets or

stars. The sun's hour angle is found as follows:

Sun's hour angle = Mean Time at Ship + "E".

The hour angle of all other bodies is found as follows:

$$\text{Hour angle} = \text{Mean Time at Ship} + \text{"R"} \sim \text{R.A. of body.}$$

As explained in Chapter Five, longitude in the celestial concave is expressed by Right Ascension or R.A. The hour angle of any body is the angle at the pole between the observer's meridian and the meridian passing through the body; in other words, the difference in longitude between the observer and the body.

The longitude of the observer has therefore to be expressed in the same terms as the longitude of the body in order to find the difference in longitude or hour angle between the two.

This is done by finding the R.A. of the observer's meridian or R.A. Mer. The formula for this is as follows:

$$\text{M.T.S.} + \text{"R"} = \text{R.A. Mer.}$$

It is therefore only necessary, having taken the azimuth of the body to enter the tables with the three factors required.

The latitude is found by dead reckoning from the last observation also the longitude which is used to find the M.T.S. The declination is found from the *Nautical Almanac* for the G.M.T. of the observation, and the hour angle is found as described above.

Entering the tables at the latitude, either same name, or contrary name to declination, as explained for amplitudes, look down the declination column for the declination found until opposite the hour angle found. If the azimuth taken was of the sun and apparent time before 12 hours the true azimuth is found by referring to the times in the column at the left of the page, but, if the apparent time was after noon it is found by referring to the times in the column at the right of the page.

If the azimuth taken was of any body other than the sun the hour angle is looked up in the column to the right of the page.

In star azimuth tables where the declinations covered are greater than the sun's maximum declination the time column is given in hour angle only. It is usually necessary to interpolate, not only for the latitude and declination but also for the hour angle in order to get an accurate result.

Correction to Altitude.—It is necessary before going any further to consider the corrections to be applied to observed altitudes of bodies to convert them to true altitudes.

Corrections to observed altitude can be found in tables in Norie's tables or Inman's tables or most nautical tables. They are given in different tables according to the object being observed and although the difference between observed and true altitude is due to various causes, the total correction is given in the various tables.

The total correction can be found for the sun, or for planets and stars, or for the moon. Sextants also sometimes have a correction, known as index error, which varies with the observed altitude; this correction can be found in the lid of the instrument and is always applied before applying the total correction whatever body has been observed.

The total correction given in the tables for the sun includes that for Dip or height of the observer's eye above sea level, refraction or the amount a ray of light is deflected in passing through the atmosphere, semi-diameter or the angle at the observer between the centre of the sun and its edge nearest the horizon. The centre of the sun is the point required for the true

altitude but it is easier to observe the edge nearest the horizon and apply the semi-diameter, and parallax or the angle at the sun between the observer and the centre of the earth. This total correction is found in the tables with a small additional monthly correction at the foot of the tables to allow for the change in diameter of the sun during the year; it is nearly always additive except at very low altitudes with a fairly large height of eye which are marked as subtractive in the tables.

The total correction given in the tables for planets and stars includes only corrections for Dip and Refraction. Semi-diameter and parallax are so minute that they are ignored. The correction is always subtractive. The total correction for the moon however is a complicated business owing to its comparative proximity to the earth.

Tables are given in Norie's and Inman's nautical tables for this correction, in which it is necessary to enter the tables with the observed altitude and also the horizontal parallax which is found for the day on page two of the month in the *Nautical Almanac*.

The table is given in two parts according to whether the upper limb or edge of the moon has been observed or the lower. There is also a small additional correction for height of eye

given at the bottom of the page. The correction for the lower limb is always additive while the correction for the upper limb is either additive or subtractive as denoted in the tables.

Observations of the moon are difficult to take but are frequently very valuable during the day, since they can be taken practically simultaneously with observations of the sun and an accurate position obtained.

Venus can also be observed during the daytime under good conditions with a good sextant. The mean time of the meridian passage of Venus can be looked up in the *Nautical Almanac* and by comparison between M.T.S. and ship's time can be observed when on the meridian. The approximate altitude is 90° — D. Lat. between the observer and Venus, + Star's correction for altitude. Under perfect conditions with an excellent sextant I have taken observations of Jupiter during the day but the conditions necessary are rare whereas many navigators take daylight observations of Venus regularly. The great thing to remember is that the sun's correction is nearly always additive while the star's is subtractive.

Meridian Altitudes.—If the altitude of a body is observed accurately with a sextant when

that body is bearing either True North or True South of the observer the observer's latitude can be calculated very simply and with great accuracy. When a body is bearing True North or True South of the observer it is said to be on the observer's meridian and the observation is known as a meridian altitude.

If the corrected altitude of a body is subtracted from 90° the difference of latitude between the observer and the body is found. The latitude of the body can be found from the *Nautical Almanac* and is referred to as its declination. By applying this difference of latitude between the observer and the body to the declination the latitude of the observer can be found. This difference of latitude is applied in the same way as the difference of latitude between two places on the earth's surface.

EXAMPLE

True Altitude of Sun = 80° bearing North.
Subtract from 90° = 10° South D.Lat.
Declination of Sun = 20° North.
Latitude of observer = 10° North.

Or, again—

True Altitude of Sun = 80° bearing South.
Subtract from 90° = 10° North D.Lat.
Declination of Sun = 20° North.
Latitude of observer = 30° North.

The time when a body will be on the meridian can easily be calculated. In the case of the sun find out the apparent time of ship at a certain time and compare it with the time kept on the ship's clocks, the difference will be the difference between the time when the sun is on the meridian and 12 hours ship's time.

EXAMPLE

The ship's time is one hour ahead of G.M.T.

At 11 00 hours ship's time G.M.T. is 10 00 hours.

Longitude at 12 00 hours A.T.S. will be about 14° 15′ West.

Apply this to the G.M.T. at 10 00 hours
= 09h. 03m. 00s. M.T.S.

Add "E" 12h. 06m. 30s. to the M.T.S.
= 21h. 09m. 30s. A.T.S.

At 11 00 hours ship's time it is therefore 02h. 50m. 30s. from apparent noon. Apparent noon is therefore 13h. 50m. 30s. ship's time.

The time when a star or planet is on the meridian is found by looking up its R.A. in the *Nautical Almanac.* Since when it is on the meridian the R.A. of the Meridian will be the same as the star's R.A. and therefore R.A. star = R.A. Mer. = M.T.S. + "R," the M.T.S. when the star is on the meridian is equal to star's R.A. − "R." It may be necessary to add

24 00 hours to the stars R.A. in order to make subtraction possible.

Having the M.T.S. when the star is on the meridian it is easily converted to ship's time, as explained above, the difference between M.T.S. and G.M.T. being compared with the difference between ship's time and G.M.T.

The more usual method is to work out the approximate time of twilight, as described in Chapter Five, and taking the R.A. Mer. for that time look in the *Nautical Almanac* on the first page of the month down the column giving the R.A. of the stars. If the R.A. of one of the stars is within a few minutes of the R.A. Mer. then it can be taken and worked out as a meridian altitude or possibly as an ex-meridian altitude as described later in this chapter. If the star's R.A. is less than the R.A. Mer. the star will not be on the meridian until after the time for which the R.A. Mer. is worked, if greater, it will be on the meridian before.

Meridian altitudes for the sun, planets and stars are worked out in the same way, the only difference being the correction to the observed altitude to convert it to true altitude.

Ex-Meridian Altitudes are observations for altitude taken of bodies when they are near

the observer's meridian and when for some reason or another it is not either possible or convenient to take a meridian altitude.

In the case of the sun on a cloudy day there is a possibility of the sun being obscured when it is on the meridian, and so an ex-meridian altitude should be taken in order to make sure of getting a latitude observation. In the case of stars they are frequently not on the meridian at the time during twilight when conditions are most suitable for observation, but they may be sufficiently near the meridian to take an ex-meridian altitude.

The method of finding the limits at which ex-meridian altitudes can be taken is very simple, it is merely the D. Lat. in degrees between the observer's latitude and that of the body expressed in minutes of time. One degree of D. Lat. equalling one minute of time.

EXAMPLE

Sirius is on the meridian at 05h. 30m. ship's time

Decl. of Sirius	=	16° 37′ S.
Lat. of observer	=	34° 23′ N.
D. Lat.	=	51° 00′

The limits for taking an ex-meridian altitude are therefore from 51 minutes before to 51 minutes after 05h. 30m. ship's time.

Ex-meridian altitudes are sometimes called Reduction to meridian altitudes and this expresses rather more clearly the nature of the observations. Ex-meridian tables are given in Norie's nautical tables and also Inman's, and consist of two or more sections. The first section is entered with the observer's D.R. Latitude and the Declination of the body observed; this section is in two parts according to whether the latitude and declination are of the same or different names in the same way as the azimuth tables.

This gives a factor known as "A" which is the change in altitude for one minute from meridian passage. Taking the factor "A" and entering the second section with "A" and the time before or after the meridian passage in minutes the reduction to the meridian can be found in minutes of arc.

There is a further correction to this in section three for altitude. Add this reduction to the corrected altitude or true altitude and work the problem out as an ordinary meridian altitude.

EXAMPLE.—An ex-meridian altitude is taken of Sirius at 05h. 30m. ship's time.

Sirius Obs. Alt.	49° 10′	G.M.T.	02h. 10m. 30s.
Total Corrn.	− 07′	Long. E.	03h. 30m. 00s.
Sirius T. Alt.	49° 03′	M.T.S.	05h. 40m. 30s.
		"R"	01h. 09m. 30s.
		R.A. Mer.	06h. 50m. 00s.
		R.A. Sirius	06h. 42m. 00s.
		Hour angle	00h. 08m. 00s.

Ship's D.R. Position at 05h. 30m. ship's time.
Lat. 34° 30′ North.
Long. 52° 30′ East.
Decl. of Sirius 16° 37′ South.

Enter ex-meridian Table 1 in Norie's with Lat. 34° 30′ N. and Decl. 16° 37′ S.
"A" = 2.0

Enter Table 2 with "A" 2.0 and hour angle 08m. 00s. Reduction = 2.1′.

T. Alt.	= 49° 03′ bearing South.
Reduction	= + 02′
Mer. Alt.	= 49° 05′ bearing South.
Subtract from 90°	= 40° 55′ North D. Lat.
Decl. of Sirius.	= 16° 37′ South.
Latitude.	= 34° 18′ North.

CHAPTER SEVEN

Marcq St. Hilaire method—Sun observations

The Marcq St. Hilaire or position line method of navigation is almost universally adopted now, and has many advantages over previous alternative methods.

It is based on the principle that there is a position on the earth's surface which is directly beneath a celestial body being observed at the exact time at which the observation was taken. The observed altitude of this body corrected to true altitude and subtracted from 90° gives the geographical distance from the observer to this spot at the exact time at which the observation was taken.

Now if the G.M.T. was noted accurately at the time of this observation the exact position of this spot on the earth's surface directly beneath the body can be determined, and from this the geographical distance between this spot and the D.R. position of the ship can be calculated.

If the geographical distance from the observer to this spot as found by the sextant is greater than the geographical distance as calculated from the D.R. position, then the

D.R. position must be incorrect to the amount of the difference in a direction away from the bearing of the spot. If the geographical distance from the observer to the spot as found by the sextant is less than the geographical distance as calculated from the D.R. position, then the D.R. position must be incorrect to the amount of the difference in a direction towards the bearing of the spot.

The true bearing of the spot is the same as the true azimuth of the body and can therefore be found in the azimuth tables.

The geographical distance from this spot does not, however, give an exact position. This geographical distance is only the radius of a circle of which the spot is centre, and all that is known is that the ship is somewhere on the circumference of this circle. The difference between the geographical distance as found by sextant and the geographical distance as calculated from the D.R. position is only the distance in geographical miles that the D.R. position is from this circle.

Since the circle is a large one the arc of this circle near the D.R. position can be drawn as a straight line with practically no loss in accuracy and can be used as a position line or line on which the ship is known somewhere to be.

This difference between the calculated geographical distance or G.D. and the true G.D. as found by the sextant is known as the intercept. If the true G.D. is less than the calculated G.D. the intercept is towards the spot, if greater, it is away from it.

By plotting the D.R. position on a chart or piece of paper and drawing the intercept on a line of bearing towards or away from the spot, a position line on which the ship is known to be can be drawn at right angles to the bearing line through the point on the bearing line at the end of the intercept.

If other observations can be taken at almost the same time and with a fairly large difference of bearing from the first, other position lines can be drawn in relation to the D.R. position; where these position lines cut each other is the observed position of the ship. (See Fig. 13.)

This is the most accurate method of navigation by nautical astronomy and is most useful when finding a position by star observations.

Another method of using the same principle with the sun is to take an early observation of the sun and plot it down, then later when the bearing of the sun has changed a fair amount take another observation and plot it down. By carrying the first position line forward to the

second D.R. position, the two position lines can be drawn in relation to the second D.R. position; where the two position lines cut is the

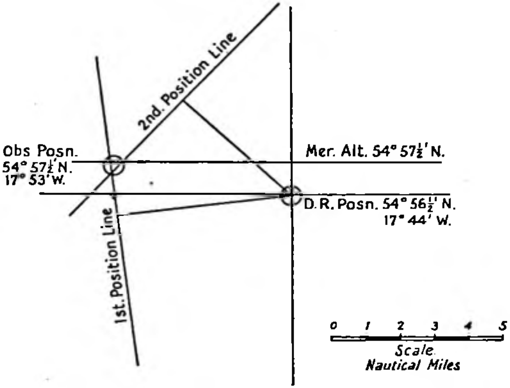

FIGURE 13

position of the ship at the time of the second observation. (See Fig. 13.)

On the next page is an example of observations of the sun worked by the Marcq St. Hilaire method and verified by a meridian altitude.

M.T.S. + "E" = H.A.T.S. which is the Hour Angle of the True Sun which is measured

At 08 30 ship's time the observed altitude of the sun's lower limb was 19° 50¼′ at G.M.T. 07h. 30m. 10s. Height of eye 16 ft.

Last fix.	54° 25′ N.	12° 34′ W.	Run since then 136 miles on N. 80° W. (T).
	23½′ N.	3° 50½′ W.	136 on N. 80° W. = 23·6 D. Lat. 133·9 Dep.
			133·9 Dep. = 230·5 D. Long. at Lat. 54½°.
D.R. Posn.	54° 48½′ N.	16° 24½′ W.	

G.M.T.	= 07 30 10		Obs. Alt.	= 19° 50¼′
Long. W.	= 01 05 38		Total Corr.	= + 9½′
M.T.S.	= 06 24 32		True Alt.	= 19° 59¾′
"E"	= 12 01 28		True G.D.	= 70° 00¼′
H.A.T.S.	= 18 26 00	subtract from 24 hours.	Cal. G.D.	= 69° 55¼′
E.H.A.	= 05 34 00	Log.Hav. = 9·64679	Intercept.	= 5′ Away
Latitude	54° 48½′ N. Cos.	= 9·76066		
Declination	20° 11½′ N. Cos.	= 9·97245	Sun's true bearing N. 83° E.	
Change this from the	Log. Hav.	= 9·37990	Intercept 5′ Away.	
in Hav. tables to the	Nat. Hav.	= 0·23983		
Lat. ± Dec. 34° 37′	Nat. Hav.	= 0·08851		
Calculated G.D. =	Nat. Hav.	= 0·32834 = 69° 55¼′		

At 12 00 hours ship's time the observed altitude of the sun's lower limb was 47° 50′ at 11h. 00m. 50s. G.M.T. Height of eye 16 ft.

Last fix.	= 54° 25′ N.	12° 34′ W.	Run since then 161 miles on N. 80° W.
	28′ N.	4° 33′ W.	161 on N. 80° W. = 158.6 Dep. 28.0 D. Lat.
			158 6 Dep. = 273′ D. Long. at Lat. $54\frac{1}{2}$°.
D.R. posn.	= 54° 53′ N.	17° 07′ W.	

G.M.T.	= 11 00 50	Obs. Alt.	= 47° 50′
Long. W.	= 1 08 28	Total Corrn.	= +11′
M.T.S.	= 09 52 22	True Alt.	= 48° 01′
"E"	= 12 01 26	True G.D.	= 41° 59′
		Cal. G.D.	= 41° $54\frac{3}{4}$′

H.A.T.S.	= 21 53 48 subtract from 24 hours.			
E.H.A.	= 02 06 12	Log.Hav.	= 8.86869	Intercept = $4\frac{1}{4}$′ Away
Latitude	54° 53′ N.	Cos.	= 9.75985	
Declination	20° 12′ N.	Cos.	= 9.97243	
Change this from the		Log.Hav.	= 8.60097	Sun's true bearing S 47° E. Intercept $4\frac{1}{4}$′ Away.
in Hav. tables to the		Nat.Hav.	= 0.03990	
Lat. ± Dec. 34° 31′		Nat.Hav.	= 0.08802	
Calculated G.D.		Nat.Hav.	= 0.12792 = 41° $54\frac{3}{4}$′.	

from noon to noon. Therefore in order to get the hour angle from the noon of that day it is necessary to subtract it from 24 hours when it is less than 24 hours and subtract 24 hours from it when it is more than 24 hours.

At 12 00 hours ship's time a second observation of the sun's lower limb was taken.

These two observations of the sun are plotted in Fig. 13 with a meridian altitude taken when the sun was on to the meridian to verify them.

It will be seen that the two position lines cut at a point one nautical mile North and five nautical miles west of the D.R. position at 14 09 hours ship's time. The distance West is converted to D. Long. by looking in the Traverse table at the latitude 55°, the distance West is looked up in the D. Lat. column and the D. Long. against it in the Distance column which is found to be nine minutes West.

The observed position at 14 09 ship's time is therefore 54° 57½′ N.
17° 53′ W.

At 14 09 hours ship's time a meridian altitude of the sun's lower limb was taken, the working of which is shown on the next page.

At 14h. 09m. ship's time the meridian altitude of the sun's lower limb was 55° 03½′. Height of eye 16 ft.

Last fix.	54° 25′ N.	12° 34′ W.	Run since then 182 miles on N. 80° W.
	31½′ N.	5° 10′ W.	182 on N. 80° W. = 179·2 Dep. 31·6 D. Lat.
			179·2 Dep. = 310′ D. Long. at Lat. 54¾.
D.R. Posn.	54° 56½′ N.	17° 44′ W.	

Obs. Alt.	55° 03½′	
Total Corrn.	11½′	
True Alt.	55° 15′	bearing South.
	90° 00′	
D. Lat.	34° 45′	North.
Decl.	20° 12½′	North.
Latitude =	54° 57½′	North.

CHAPTER EIGHT

Star observations—Latitude by Pole Star—Moon and Planet observations

A position found by three or more star observations is the most accurate method of celestial navigation; this is especially the case in the North Atlantic in high latitudes in the winter.

The sun can be used as a very useful check to star sights and a good latitude can be obtained by a meridian altitude at noon but it is not very accurate for fixing a position. It rises late, does not attain a very high altitude, and has a small and slow change of bearing, therefore a small inaccuracy in the run between sights causes a large inaccuracy in the position found. This is especially the case in war-time when ships have to zigzag.

Star sights are taken almost simultaneously and therefore do not suffer from any inaccuracy in the run between sights.

Star, moon and planet observations can all be worked out by the same Marcq St. Hilaire formula as the sun; the only difference being in the finding of the hour angle and the correc-

tion to the observed altitude. The latter is explained in Chapter Six and the former is explained in Chapters Five and Six. Examples will however be given in this chapter, which should make the working quite clear.

The best method, having worked out beforehand the time at which the stars can be taken, as explained at the end of Chapter Five, and having worked out the approximate bearings and altitudes of the five brightest, is to take observations of at least three of them. These three should have a difference in bearing from each other of about 60 degrees in order to get a good cut. Take also whenever possible an observation of the Pole Star as a check, the method of working this is explained later in this chapter.

At 06 00 hours ship's time the observed altitude of Altair was 25° 50′ at 07h. 15m. 15s. G.M.T. Height of eye 16 feet (see next page).

Owing to the fact that the star's R.A. is greater than the R.A. Mer. we know that the star is East of the meridian and therefore the azimuth is to the East. Owing to the intercept being nil, the position line runs through the D.R. position in a direction at right angles to S. 67° E.

At 06 01 hours ship's time the observed

At 06 00 hours ship's time the observed altitude of Altair was 25° 50′ at 07h. 15m. 15s. G.M.T. Height of eye 16 ft.

The D.R. position at 06 00 hours ship's time was 55° 10′ N. 19° 15′ W.

G.M.T.	= 07 15 15			Obs. Alt.	= 25° 50′
Long. W.	= 01 17 00			Total Corr.	= − 06′
M.T.S.	= 05 58 15			True Alt.	= 25° 44′
"R"	= 10 02 25				
				True G.D.	= 64° 16′
R.A.Mer	= 16 00 40			Cal. G.D.	= 64° 16′
Star's R.A.	= 19 47 20				
				Intercept.	= Nil.
Star's H.A.	= 03 46 40	Log. Hav.	= 9·352660		
Decl.	= 8° 41′ N.	Cos.	= 9·994993		
Lat.	= 55° 10′ N.	Cos.	= 9·756782		
Change this from the		Log. Hav.	= 9·104435		
in Hav, tables to the		Nat. Hav.	= 0·12719	True bearing Altair S. 67° E.	
Lat. ± Dec. = 46° 29′		Nat. Hav.	= 0·15572	Intercept Nil.	
Calculated G.D.		Nat. Hav.	= 0·28291 = 64° 16′		

At 06 01 hours ship's time the observed altitude of Arcturus was 49° 00′ at 7h. 16m. 20s. G.M.T. Height of eye 16 ft.

The D.R. position at 06 01 hours ship's time was 55° 10′ N. 19° 15′ W.

G.M.T.	= 07 16 20				Obs. Alt.	= 49° 00′
Long. W.	= 01 17 00				Total Corr.	= − 05′
M.T.S.	= 05 59 20				True Alt.	= 48° 55′
"R"	= 10 02 25					
					True G.D.	= 41° 05′
R.A. Mer.	= 16 01 45				Cal. G.D.	= 41° 09½′
Star's R.A.	= 14 12 27					
					Intercept.	= 4½′ Towards.
Star's H.A.	= 01 49 18	Log. Hav.	= 8·746570			
Decl.	= 19° 33′ N.	Cos.	= 9·974212			
Lat.	= 55° 10′ N.	Cos.	= 9·756782			
Change this from the		Log. Hav.	= 8·477564			
In the Hav. tables to the		Nat. Hav.	= 0·03003	True bearing Arcturus S. 41° W.		
Lat. ± Dec. = 35° 37′		Nat. Hav.	= 0·09353	Intercept 4½′ Towards.		
Calculated G.D.		Nat. Hav.	= 0·12356 = 41° 09½′			

altitude of Arcturus was 49° 00′ at 07h. 16m. 20s. G.M.T. Height of eye 16 feet (see page 86).

Owing to the fact that the star's R.A. is less than the R.A. Mer. we know that the star is West of the meridian and that therefore the azimuth is to the West. The intercept is towards S. 41° W. 4½ miles and the position line is laid off at right angles to this point.

In Fig. 14 the position lines from these two observations are drawn, the observed position being where they cut. A latitude by Pole Star is taken as a check.

At 06 02 hours ship's time the observed

The observed position from the observations of Altair and Arcturus was:

55° 05½′ N. 19° 18′ W.

G.M.T.	=	07 17 10	Obs. Alt.	=	54° 18′
Long. W.	=	01 17 12	Total Corr.	=	−4½′
M.T.S.	=	05 59 58	True Alt.	=	54° 13½′
"R"	=	10 02 25	1st Corr.	=	+51½′
R.A.Mer.	=	16 02 23			55° 05′
			2nd Corr.	=	+ ¼′
					55° 05¼′
			3rd Corr.	=	+ ¼′
			Latitude	=	55° 05½′

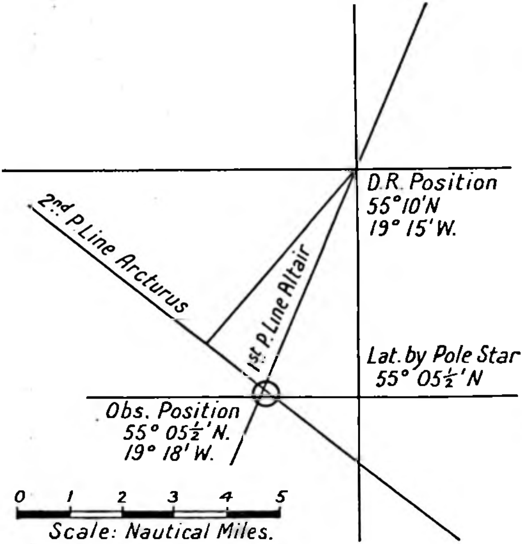
D.R. Position
55°10'N
19° 15' W.
2nd P. Line Arcturus
1st P. Line Altair
Lat. by Pole Star
55° 05½' N
Obs. Position
55° 05½' N.
19° 18' W.
0 1 2 3 4 5
Scale: Nautical Miles.

FIGURE 14

altitude of Polaris (Pole Star) was 54° 18′ at 07h. 17m. 10s. G.M.T. Height of eye 16 feet.

The Pole Star tables are found at the back of the *Nautical Almanac*. Local Sidereal Time is the R.A. Mer.

Moon and planet observations are worked up in the same way as star observations, the only difference being in finding the R.A. and Dec. of these bodies and, in the case of the moon, the correction to the observed altitude to find the true altitude.

The R.A. and Dec. of the moon is found in the *Nautical Almanac* on the pages of the month given to the moon. These are given for every two hours and have to be corrected to the nearest minute by means of the proportional parts at the end of the book.

The R.A. and Dec. of the planets is given on the last two pages of the month and is given for 00 00 hours of every day. The table of proportional parts has also to be used in order to take out these figures correctly. It should be noted that in the case of the moon the proportional parts are for every two hours and should be looked up from that side, while in the case of the planets it is for 24 hours from midnight to midnight G.M.T. and should be looked up on the other side.

The correction to the observed altitude for planets is the same as that for stars but the correction for the moon is considerably different as is explained in Chapter Six.

It will be found with a little practice that stars are quite easy to observe and to work out and will invariably give a better position owing to the fact that there is no run between sights.

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